Final Report
NASA Grant NAG1-01-028

NONLINEAR AND FAILURE ANALYSIS OF COMPOSITE STRUCTURES

Submitted to:

National Aeronautics and Space Administration
Langley Research Center
Acquisition Division
Hampton, VA 23681-0011

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December 2002

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CONTRACTUAL INFORMATION

A final report submitted to National Aeronautics and Space Administration.

Title: Nonlinear and Failure Analysis of Composite Structures

Date Submitted: December 2000

Submitted by: Old Dominion University

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Duration: January 1, 2001 – December 31, 2002

Amount: $80,000

Submitted to any
other sponsor: No

Old Dominion University is an educational institution participating
in the Federal Demonstration Project.

NONLINEAR AND FAILURE ANALYSIS OF COMPOSITE STRUCTURES

Abstract

The overall goal of this research is to assess the effect of discontinuities and uncertainties on the nonlinear response and failure of stiffened composite panels subjected to combined mechanical and thermal loads. The key elements of the study are: a) study of the effects of stiffener geometry and of transverse stresses on the response, damage initiation and propagation in stiffened composite panels; b) use of hierarchical sensitivity coefficients to identify the major parameters that affect the response and damage in each of the different levels in the hierarchy (micromechanical, layer, panel, subcomponent and component levels); and, c) application of fuzzy set techniques to identify the range and variation of possible responses.

The computational models developed are used in conjunction with experiments to understand the physical phenomena associated with the nonlinear response and failure of stiffened composite panels. A toolkit is developed for use in conjunction with deterministic analysis programs to help the designer in assessing the effect of uncertainties in the different computational model parameters on the variability of the response quantities.

The Principal Investigator is Dr. Ahmed K. Noor, William E. Lobeck Professor of Aerospace Engineering, and the NASA Technical Monitor is Dr. James H. Starnes, Jr., Structures and Materials Competency, NASA Langley Research Center.

BACKGROUND AND SUMMARY OF THE RESEARCH ACTIVITIES

Stiffened composite panels are candidates for use in various components of high-speed aircraft and space transportation vehicles, such as fuselage, wing and empennage. These panels are subjected to combined temperature gradient and mechanical loading. They can have geometric discontinuities as well as discrete and terminated stiffeners. Therefore, there is a need for a systematic study of: a) the effect of discontinuities in thickness and discrete stiffeners on the global and detailed response as well as on the failure of composite panels; and b) the effectiveness of different reinforcement and stiffening strategies for composite panels.

The work performed under this grant during the period January 1, 2001 to December 31, 2002 focused on the first topic. Composite panels with geometric discontinuities, as well as discrete and terminated stiffeners were considered (see Fig. 1). The structures were subjected to combined mechanical and thermal loads. Specifically, the following tasks were performed:

1) Detailed examination of the variation of the transverse stresses in the nonlinear and post-buckling regimes;

2) Study of the effects of geometric discontinuities and discrete stiffeners on the nonlinear response (local gradients); and

3) Development of a toolkit in the form of pre- and post-processors that can be attached to any deterministic analysis program to generate the bounds of variation of response functions and quantities governing failure initiation. The toolkit uses the hierarchical sensitivity coefficients to identify the major parameters, and fuzzy set techniques to determine the variation of the response quantities resulting from a pre-selected variation in the major parameters (see Figures 2 and 3).

Effective use was made of high fidelity computational models to enhance the physical understanding of the numerical studies were conducted for both flat and cylindrical composite panels with continuous and terminated stiffeners subjected to combined pressure, mechanical and thermal loads.

For each panel, both the geometrically nonlinear response as well as the hierarchical sensitivity coefficients were generated (Figure 4). Also, the effect of variation in the major parameters on the variability of the various response quantities was investigated.

In addition, an object-oriented event-driven immersive virtual environment has been developed for the visualization of the response and sensitivity information.

The results of the research are contained in two publications and two multimedia presentations. The list of publications and presentations are given in Appendix I.

Panel Dimensions
$L_1 = 0.508$ m
$L_2 = 0.79756$ m
$R = .6096$ m (curved panels)
$h = 0.001176$ m (8 layer skin)
$h = 0.002352$ m (16 layer skin)

continuous stiffeners

Stiffener dimensions and spacing
$b = 0.0381$ m
$h_r = 0.03175$ m
$l = 0.159512$ m
   (for panels with 5 stiffeners)
$l = 0.113937$ m

terminated stiffeners

Boundary Conditions
At $x_1 = 0, L_1$
   $u_1 = \mp q_e/2$
   $u_2 = w = \phi_1 = \phi_2 = \phi_3 = 0$

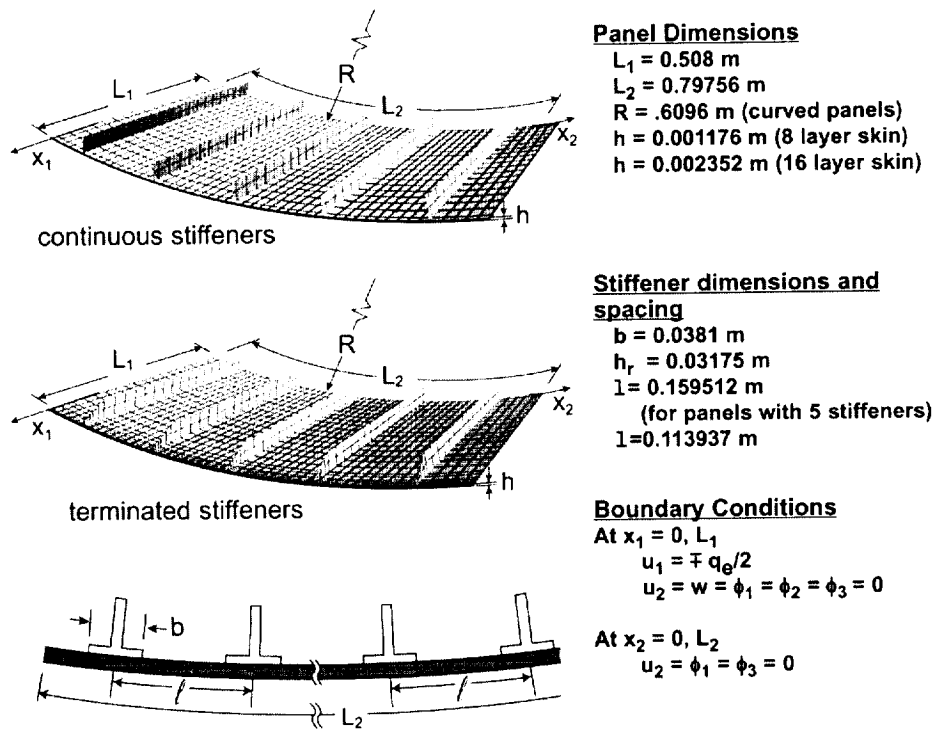At $x_2 = 0, L_2$
   $u_2 = \phi_1 = \phi_3 = 0$

Figure 1 – Panels and boundary conditions considered in the present study
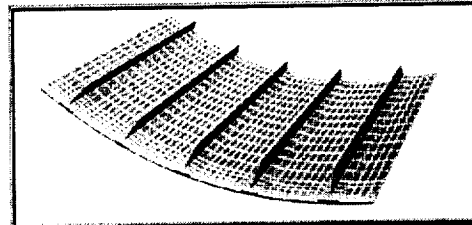
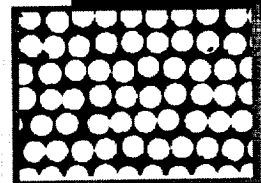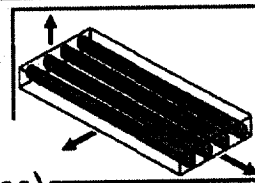Evaluate hierarchical sensitivity coefficients with respect to

○ component parameters

○ subcomponent parameters

○ panel parameters

○ effective layer parameters

micromechanical parameters
○ (fiber and matrix properties)

Identify major parameters for the response quantities
of interest, and for the quantities governing failure
initiation - treated as fuzzy sets

For a preselected variation of the major parameters
find the range of variation of the response

Figure 2 – Approach used to assess the effects of variability in material and geometric parameters on the response of composite panels.
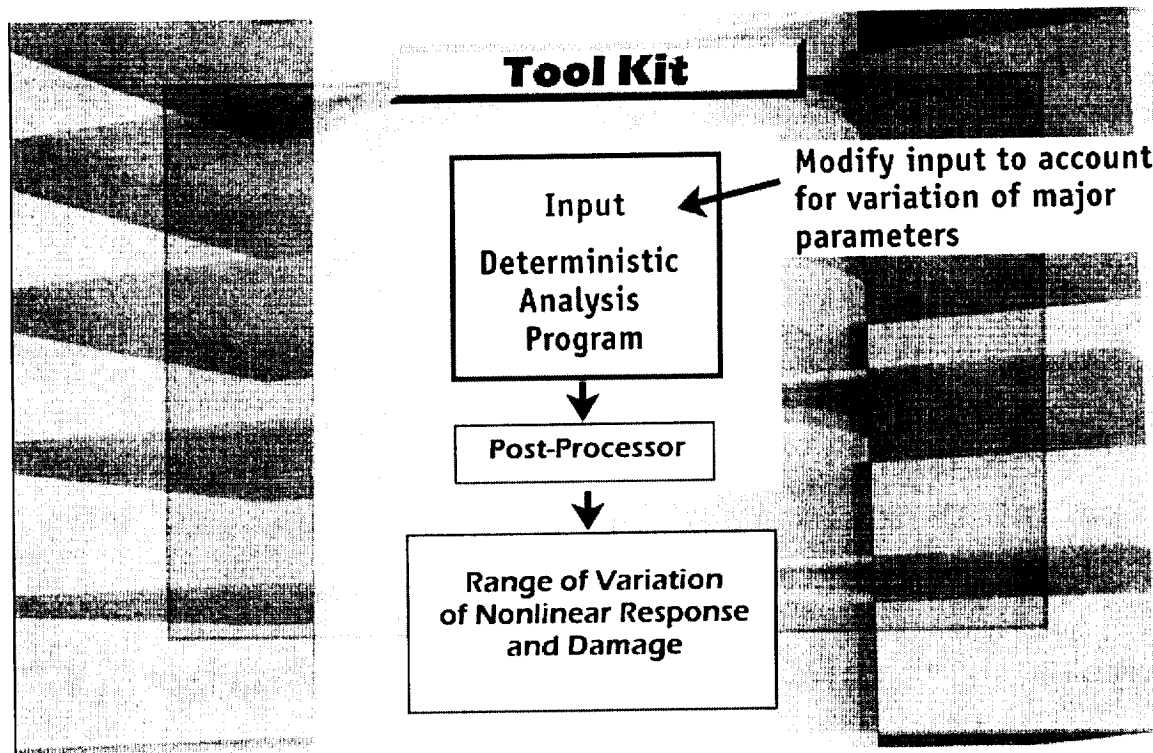
Figure 3 – Implementation of the procedure in a deterministic analysis program
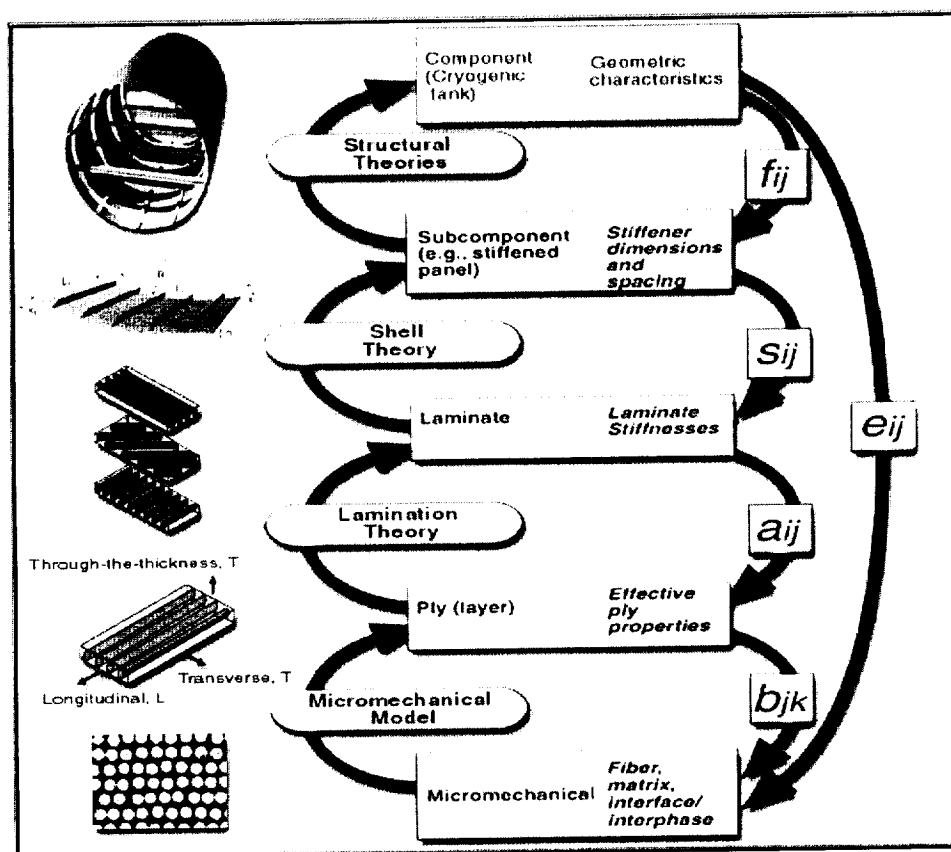

Figure 4 – Hierarchical Modeling for Multiple Structural Length Scales

APPENDIX I

Publications:

1. Noor, Ahmed K., Starnes, James H., Jr. and Peters, Jeanne M., "Nonlinear Thermomechanical Response of Composite Panels with Continuous and Terminated Stiffeners", Proceedings of the 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, April 15-18, 2001, Seattle, WA, AIAA, 2001.

2. Noor, Ahmed K., Starnes, James H., and Peters, Jeanne M., "Thermomechanical Response Variability of Stiffened Composite Panels", Proceedings from the 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Denver, CO, April 22-25, 2002, pp. 154-164, also published in the Journal of Aerospace Engineering, Vol. 15, Issue 4, October 1, 2002,

Presentations:

1. Nonlinear Thermo-mechanical Response of Composite Panels with Continuous and Terminated Stiffeners invited paper, presented at the 42nd AIAA/ASME/ASCE/AHS/ASC SDM Conference, Seattle, WA, April 16, 2001.

2. Thermomechanical Response Variability of Composite Panels with Continuous and Terminated Stiffeners, 43rd AIAA/ASME/ASCE/AHS Structures, Structural Dynamics, and Materials Conference, 10th AIAA/ASME/AHS Adaptive Structures Conference, 4th AIAA Non-Deterministic Approaches Forum, 3rd AIAA Gossamer Spacecraft Forum, Denver, CO, April 20-24, 2002.